Rev. Mexicana Astron. Astrof., 12, 249-256 (1986)

PLANETARY NEBULAE AND THE GALACTIC TEMPERATURE GRADIENT

W.J. Maciel and M. Faúndez-Abans[1]

Instituto Astronômico e Geofísico, USP
Brasil

RESUMO. Neste trabalho são analisados os gradientes de temperatura eletrônica obtidos a partir de regiões H II e nebulosas planetárias. São considerados of efeitos de (a) variações sistemáticas nas temperaturas das estrelas centrais, (b) grãos de poeira, e (c) gradientes de abundâncias de elementos pesados sobre as temperaturas eletrônicas. Conclui-se que os elementos pesados são os principais responsáveis pelos gradientes de temperatura, e é feita uma estimativa do gradiente galático de O/H.

ABSTRACT. Galactic electron temperature gradients derived both from H II regions and planetary nebulae are studied. The effects of (a) systematic variations of the central star temperature, (b) dust grains, and (c) heavy-element abundance gradients on the electron temperature are considered. It is concluded that the heavy elements are the main responsible for the temperature gradient, and an estimate is made of the galactic O/H gradient.

Key words; planetary nebulae - temperatures - gradients

I. INTRODUCTION

Recently, the presence of a galactic temperature gradient derived from a sample of planetary nebulae (PN) was proposed by Maciel and Faúndez-Abans (1984). Similar gradients have long been known from H II regions data (section 2), and their origin is usually linked to the observed gradients of heavy-element abundances. In fact, PN have been widely used to study abundance gradi-

1. On leave from Universidad de Santiago de Chile.

ents (see for example Kaler 1983; Faúndez-Abans and Maciel 1984), and the derived gradients are of the same order as the observed from H II regions.

In this work, the earlier proposition of Maciel and Faúndez-Abans (1984) is improved, and a discussion is given on the physical cause of the temperature gradient.

II. TEMPERATURE GRADIENTS FROM H II REGIONS

A positive gradient involving the electron temperature T_e of galactic H II regions and the distance R to the galactic centre projected onto the galactic plane has been initially found by Churchwell and Walmsley (1975). Presently, there are many independent radio estimates of the gradient both for high-density H II regions (EM > 10^5 pc cm^{-6}, see for example Wink et al. 1983), and low-density nebulae (see for example Azcárate et al. 1983, and references quoted therein). The temperature gradients derived from radio recombination lines are in the range 250 - 440 K kpc^{-1}.

In the optical spectrum, measurements by Peimbert et al. (1978) indicate a gradient in the same sense as shown by the radio data. However, the optical gradient is much steeper than the values quoted above, which may be partially explained by the small size of the sample studied by Peimbert et al. (1978). Recent measurements by Peimbert and co-workers seem to have a better agreement with the radio derived gradients (cf. Garay and Rodríguez 1983).

III. TEMPERATURE GRADIENTS FROM PLANETARY NEBULAE

In opposition to the H II regions, planetary nebulae include a mixture of objects with widely differing chemical, spatial, and kinematical properties.

Therefore, any study of chemical and abundance gradients for PN should include a classification scheme, such as the one initially devised by Peimbert (1978; see also Faúndez-Abans and Maciel 1984 for details and references). The classification scheme includes PN of type I (H, N-rich, with massive progenitor stars), type II (intermediate mass, circular orbits), type III (high-velocity, elongated orbits), and type IV (halo objects), and was considered by Maciel and Faúndez-Abans (1984) for the determination of the temperature gradient. The same criteria are adopted here, excluding galactic centre objects and evolved nebulae (objects having intrinsic radii r> 0.2 pc). The distances are derived from the mass-radius relationship (Maciel and Pottasch 1980; Maciel 1984), except for some objects, for which distances by Daub (1982) and Acker (1978, 1980) were considered. The electron temperatures were collect ed in the literature, and only recent values derived from (O III) forbidden line measurements were considered, no allowance being made for temperature fluctuations (for details see Maciel and Faúndez-Abans 1984).

As shown in figure 1, no correlation seems to exist between the electron temperature and galactocentric distance when all nebulae are included for which a safe classification can be made. The figure includes 28 type I objects, 59 nebulae of type II, 6 of type III and 1 of type IV, totalling 94 nebulae.

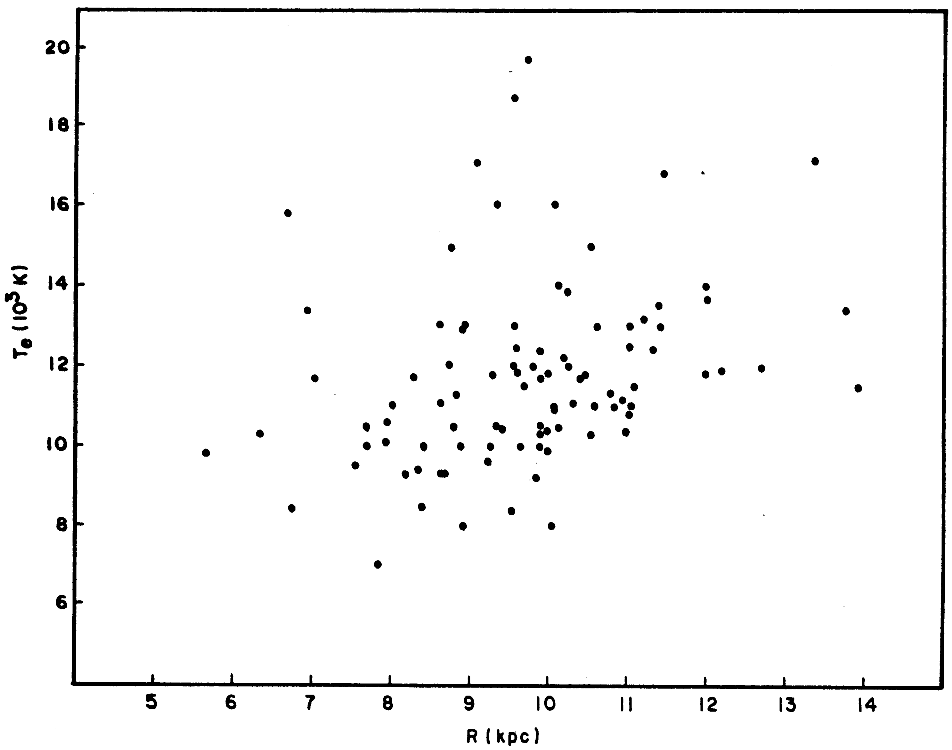

FIGURE 1. Forbidden-line electron temperature T_e against the galactocentric distance R projected onto the galactic plane for planetary nebulae of types I, II, III and IV.

In opposition, for unevolved type II nebulae, figure 2 shows that a good correlation exists, which can be written as

$$T_e = 5191 + 591\, R \qquad (1)$$

where the temperature is in K and R in Kpc. There are 53 nebulae in figure 2, and the adopted values of R and T_e are shown in table 1. The correlation coefficient is r= 0.56 and the standard deviation σ= 1318 K (Maciel and Faúndez-Abans 1984). On the other hand, similar plots for the remaining types show again no correlation between T_e and R, although the sample is now considerably smaller than for type II nebulae.

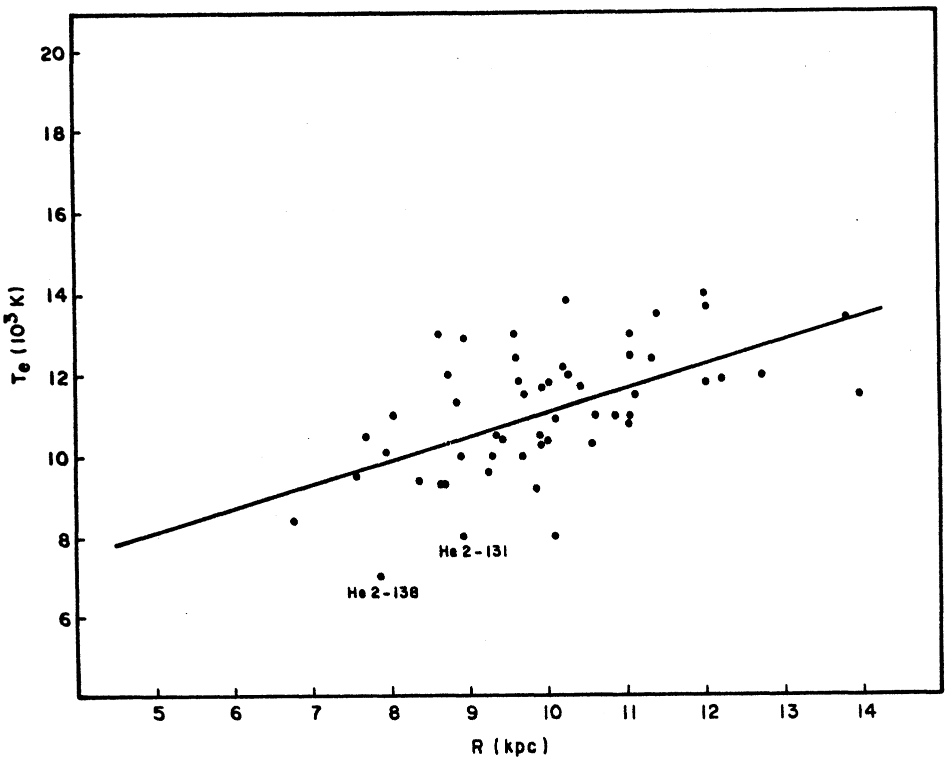

FIGURE 2. T_e against R for planetary nebulae of type II (adapted from Maciel and Faúndez-Abans 1984).

As shown by Maciel and Faúndez-Abans (1984), the correlation of figure 2 is real, and not strongly dependent on the adopted distance scale. Furthermore, a gradient of about 600 K kpc^{-1} is slightly steeper than the observed from H II regions, establishing a continuous sequence from the low-density H II regions ($T_e \simeq 3000 + 440$ R) through the high-density H II regions ($T_e \simeq 4700 +$ 380 R).

IV. THE ORIGIN OF THE TEMPERATURE GRADIENT

Three main processes have been considered in the literature as the cause of the temperature gradient: (a) systematic veriation of the central star temperature; (b) effect of dust grains, and (c) effect of the heavy-element abundances.

(a) Systematic variation of the central star temperature

Central stars having higher temperatures tend to increase the temperature of the nebula, so that any systematic veriation in the former could in principle cause a systematic variation in the latter. Central star temperatures fall usually in three classes, namely (i) effective temperature, (ii) Zanstra temperature (H or He), and (iii) Stoy temperature (see for example Pottasch 1983). The first two methods have been applied to a large number of objects, and differences in the results up to a factor 3 are not uncommon. In table 1 we show average hydrogen Zanstra temperature taken from Pottasch (1978) Pilyugin and Khromov (1979), Martin (1981), and Preite-Martinez and Pottasch (1983). The adopted Zanstra temperatures are plotted in figure 3 against the galactocentric distances.

It can be seen that no systematic variations occur, although the accuracy of each determination is low. The same conclusion follows when either He Zanstra temperatures or effective temp ratures are considered. As discussed by Maciel and Faũndez-Abans (1984), although the central star temperatures are

TABLE 1

Name	PK	R(kpc)	T_e(K)	$T_{z(H)}$(K)	Name	PK	R(kpc)	T_e(K)	$T_{z(H)}$(K)
NGC 40	120+09 1	10.44	11700	26000	NGC 7662	106-17 1	10.24	12140	66000
NGC 1535	206-40 1	11.12	11500	37000	IC 351	159-15 1	12.75	12000	44000
NGC 2022	196-10 1	12.05	13700	47000	IC 418	215-24 1	10.57	10300	35000
NGC 2371	189+19 1	11.36	12400	49000	IC 1747	130+01 1	10.64	11000	32900
NGC 2392	197+17 1	11.05	13000	27000	IC 2003	161-14 1	12.24	11900	30300
NGC 2792	265+04 1	10.28	13860	36000	IC 2149	166+10 1	11.07	11000	31000
NGC 3211	286-04 1	9.60	13020	67600	IC 2165	221-12 1	11.42	13500	60300
NGC 3242	261+32 1	10.13	10900	54000	IC 2448	285-14 1	9.62	12400	49000
NGC 3918	294+04 1	9.65	11800	69200	IC 2501	281-05 1	9.88	9200	44700
NGC 5307	312+10 1	8.65	13000	40700	IC 3568	123+34 1	11.05	10800	30500
NGC 5882	327+10 1	8.73	9300	47900	IC 4593	025+40 1	8.38	9400	29500
NGC 6210	043+37 1	9.27	9600	47500	IC 4634	000+12 1	7.59	9500	40700
NGC 6309	009+14 1	8.05	11000	-----	IC 4776	002-13 1	6.79	8400	32000
NGC 6543	096+29 1	10.08	8000	34600	IC 5117	089-05 1	10.05	11800	32000
NGC 6572	034+11 1	9.36	10500	63000	IC 5217	100-05 1	10.88	11000	56000
NGC 6720	063+13 1	9.72	11500	110000	BD 30°3639	064+05 1	9.71	10000	30000
NGC 6790	037-06 1	8.86	11300	75900	Cn 3-1	038+12 1	7.96	10100	31000
NGC 6818	025-17 1	8.77	12000	72000	Hb 12	111-02 1	11.06	12500	36400
NGC 6826	083+12 1	9.95	10300	34000	He 2-108	316+08 1	7.71	10500	24300
NGC 6884	082+07 1	9.91	10500	-----	He 2-131	315-13 1	8.95	8000	31000
NGC 6886	060-07 2	8.96	12900	-----	He 2-138	320-09 1	7.88	7000	22900
NGC 6891	054-12 1	8.93	10000	34000	Hu 1-1	119-06 1	13.98	11500	-----
NGC 7009	037-34 1	9.44	10400	60000	Hu 2-1	051+09 1	9.32	10000	38000
NGC 7026	089+00 1	10.02	10400	43800	J 320	190-17 1	13.83	13400	26700
NGC 7027	084-03 1	9.96	11700	-----	J 900	194+02 1	12.02	11800	-----
NGC 7354	107+02 1	10.29	12000	-----	M 1-1	130-11 1	12.03	14000	32800
					M 1-74	052-04 1	8.70	9300	-----

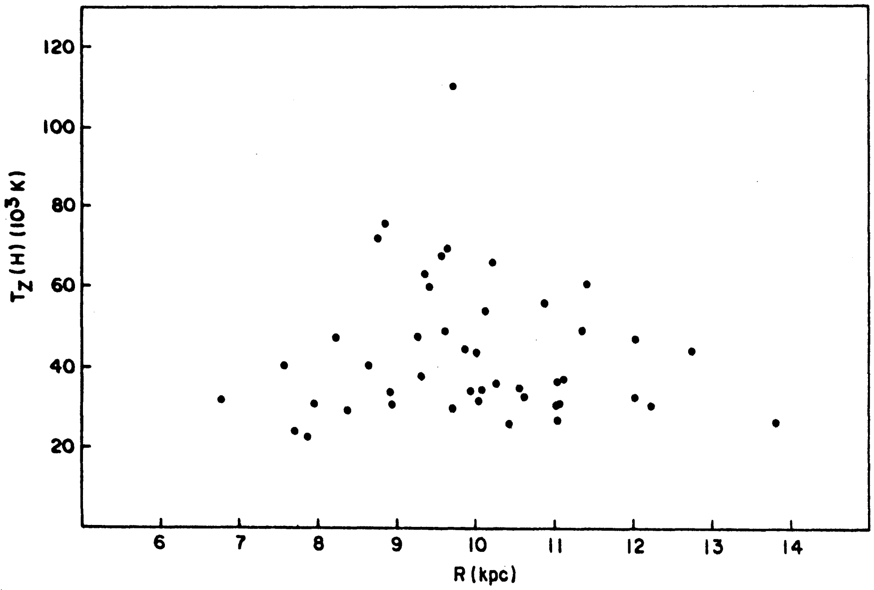

FIGURE 3. Hydrogen Zanstra temperature as a function of R for the central stars of the PN shown in table 1.

not responsible for the gradient observed in figure 2, they can in fact contribute to the observed scatter. As an example, the central stars of He 2-131 and He 2-138 have low temperatures, which may explain the position of the nebulae in figure 2.

(b) Effect of dust grains

Dust grains embedded in the ionized gas would affect the electron temperature, since they compete with H atoms for the absorption of the ionizing radiation. If the net effect of such process is a decrease in the average temperature, the grains could contribute to the observed temperature gradient, provided their galactic distribution is similar to the heavy-element distribution (section IVc). However, available calculations by Sarazin (1977) and others indicate that the cooling due to the grains is not sufficient to explain the total decrease in the electron temperature shown in figure 2. Furthermore, recent calculations by Oliveira and Maciel (1984) taking into account the photoelectric heating due to the grains (Maciel and Pottasch 1982) show that a net increase in the electron temperature may indeed occur, which would rule out the grains as responsible for the gradient shown in figure 2. Such increase can be as high as 10% in T_e, depending on the position of the central star on the HR diagram. On the other hand, it should be kept in mind that the contribution of dust is sensitive to the frequency dependence of the absorption cross section and of the photoelectric yield, both of which are poorly known. Therefore, any conclusion involving dust grains must be viewed with care.

(c) Heavy-element abundance gradients

As mentioned in the Introduction, abundance gradients of heavy-elements such as He/H, O/H, etc., are relatively well established both from measurements of H II regions and planetary nebulae. Such gradients behave inversely compared with the gradient in T_e shown in figure 2, and are generally thought to be the main responsible for the temperature gradients obtained from H II regions. In fact, heavy-element cooling dominates the cooling function, qualitatively explaining the behavior of figure 2.

Recent calculations by Faúndez-Abans and Maciel (1984) confirm the radial gradients of He/H and O/H on the basis of the same type II planetary nebulae shown in table 1. The sample is larger than previously considered in the literature, and the obtained gradient for O/H is

$$\frac{d\ \log(O/H)}{dR} = -0.09\ \mathrm{Kpc}^{-1} \tag{2}$$

On the other hand, an average T_e x (O/H) relation has been given for H II regions (cf. Mezger et al. 1979):

$$\log(O/H) \simeq -1.8 - 2\ 10^{-4}\ T_e \tag{3}$$

where T_e is in K. As a first approximation, we can assume (3) to be valid for PN, so that equations (1) and (3) would imply an abundance gradient

$$\frac{d\ \log(O/H)}{dR} = -0.12\ \mathrm{Kpc}^{-1} \tag{4}$$

which is in good agreement with the value (2) derived by Faúndez-Abans and Maciel (1984). Considering that the O/H ratio is a good measure of the heavy-element abundance, it seems safe to conclude that the electron temperature gradient shown in figure 2 is a consequence of the observed heavy-element abundance gradients.

ACKNOWLEDGEMENTS

This work was partially supported by FAPESP and CNPq (Brasil).

REFERENCES

Acker, A. 1978, Astr. and Ap. Suppl. Ser. 33, 367.
Acker, A. 1980, Astr. and Ap. 89, 33.
Azcárate, I.N., Cersósimo, J.C., Colomb, F.R. 1983, III Reunión Latinoamericana de Astronomía, Buenos Aires.
Churchwell, E., Walmsley, C.M. 1975, Astr. and Ap. 38, 451.
Daub, C.T. 1982, Ap. J. 260, 612.
Faúndez-Abans, M., Maciel, W.J. 1984, IV Reunión Latinoamericana de Astronomía, Rio de Janeiro.
Garay, G., Rodríguez, L.F. 1983, Ap. J. 266, 263.
Kaler, J.B. 1983, IAU Symposium No. 103, ed. D.R. Flower, Reidel.
Maciel, W.J. 1984, Astr. and Ap. Suppl. Ser. 55, 253.
Maciel, W.J., Faúndez-Abans, M. 1984, preprint.
Maciel, W.J., Pottasch, S.R. 1982, Astr. and Ap. 106, 1.
Martin ,W. 1981, Astr. and Ap. 98, 328.
Mezger, P.G., Pankonin, V., Schmid-Burgk, J., Thum, C., Wink, J.E. 1979, astr. and Ap. 80, L3.
Oliveira, S., Maciel, W.J. 1984, IV Reunión Latinoamericana de Astronomía, Rio de Janeiro.

Peimbert, M. 1978, IAU Symposium No. 76, ed. Y. Terzian, Reidel.
Peimbert, M., Torres-Peimbert, S., Rayo, J.F. 1978, Ap. J. 220, 516.
Pilyugin, L.S., Khromov, G.S. 1979, Soviet Astron. 23, 425.
Pottasch, S.R. 1978, IAU Symposium No. 76, ed. Y. Terzian, Reidel.
Pottasch, S.R. 1983, IAU Symposium No. 103, ed. D.R. Flower, Reidel.
Preite-Martinez, A., Pottasch, S.R. 1983, Astr. and Ap. 126, 31.
Sarazin, G.L. 1977, Ap. J. 211, 772.
Wink, J.E., Wilson, T.L., Bieging, J.H. 1983, Astr. and Ap. 127, 211.

M. Faúndez-Abans and W.J. Maciel: Instituto Astronômico e Geofísico da USP, Caixa Postal 30.627, CEP 01051, São Paulo SP, Brasil.